ENGINEERING GUIDANCE REPORT

Renewable Energy Production from DoD Installation Solid Wastes by Anaerobic Digestion

ESTCP Project ER-200933

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14. ABSTRACT

Food waste generation and disposal is a significant source of greenhouse gas emissions and lost opportunity for energy recovery. Anaerobic digestion of food waste and purification of methane-rich biogas was conducted at the US Air Force Academy. Cost and performance of the technology with respect to renewable energy efficiency; biogas purification; digester capacity and stability; waste sludge generation and characteristics; operational reliability, safety, and ease of use; and greenhouse accounting were evaluated. Demonstration results indicated the process was capable of meeting or exceeding most performance objectives. The technology was capable of significant reductions in the solid waste stream while at the same time recovering energy that can be used as vehicle fuel or a variety of other uses. Cost-effectiveness of the technology was comparable or better to landfilling and composting especially for larger installations. The technology was also demonstrated to have favorable greenhouse gas offsets compared to composting and landfilling. An engineering guidance document was prepared that provides installations practical approaches for technology evaluation and implementation.

15. SUBJECT TERMS

Food waste, FOG, solid waste, anaerobic digestion, methane, biogas, biomethane, biogas purification, vehicle fuel, renewable energy, net zero, greenhouse gas, food-to-fuel.

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1.0 INTRODUCTION

This project demonstrated both the technological and the economic viability of anaerobic digestion of Department of Defense (DoD) wastes including pre- and post-consumer food waste, waste cooking oil, and grease trap waste as a viable means of disposal and renewable energy generation. The project demonstrated the ability to digest these wastes in a controlled and predictable manner to maximize the generation of biogas, a methane-rich, high energy product. The project also evaluated the economic viability and potential greenhouse gas offsets with the technology especially when biomethane was used as vehicle fuel. Full details of the ESTCP demonstration can be found in the Final Report (Evans et al. 2016). This document provides engineering guidance for DoD installations considering implementing of the technology.

2.0 BACKGROUND

The DoD is a significant consumer of energy and generator of solid waste. During FY 2009 the DoD consumed 209 trillion BTUs of energy (2.2×10^{17} J), excluding vehicle fuel (DoD 2010). Further, during the same period the DoD generated 5.2 million tons of solid waste. The consumption of energy and the generation of waste place economic, environmental and social burdens on the DoD. In recognition of the burden that these activities place on the Department, the DoD has initiated programs and policies to reduce energy consumption and waste generation.

- The Energy Policy Act of 2005 (EPACT) mandates that federal facilities receive at least 7.5% of their electricity from renewable resources by 2013. If the energy is generated on site from renewable resources the facilities receive double credit toward attainment of this goal.
- The 2008 National Defense Authorization Act (NDAA) implemented a renewable energy goal of 25% for the DoD.
- Executive Order 13423 requires that at least half of the statutorily required renewable energy consumed by the agency in a fiscal year comes from a new renewable source and to the extent feasible, the agency implement renewable energy generation projects on agency property for agency use. Further, the order requires increased diversion of solid waste as appropriate and maintenance of cost effective waste prevention and recycling programs in its facilities (USDOE 2008).
- The DOD Integrated (Non-Hazardous) Solid Waste Management Policy set minimum standards of 40% waste diversion of non-hazardous, non-construction and demolition integrated solid waste (Beehler 2008).

This project demonstrated utilization of anaerobic digestion to treat DoD wastes and produce renewable energy that can offset an installation's energy demands and reduce its waste disposal rate. This project was measured against 30 performance objectives identified prior to the commencement of the research project. In total, the project met most of these objectives. Most notably, the project met objectives related to the following objectives:

- Energy Conversion
- Methane Production
- Natural Gas Specifications
- Loading Rate
- Solids Destruction
- Safety
- Ease of Use

The first three objectives from the list above were important as they showed that the process could be efficient, produce a valuable fuel that could be purified into a common fuel – compressed natural gas (CNG). Further the loading rate and the solids destruction objectives proved that a target loading rate could be achieved and that the process would significantly reduce the mass of

product for ultimate disposal. Safety is always paramount so by showing that the process was safe and further easy to use, it proved that it could be implemented at a DoD installation.

By using the data obtained from the study, full-scale implementation was costed. The costs identified that significant amount of capital would need to be utilized to get the project started. However, the cost savings were significant enough that the project was competitive with common food waste disposal methods. In all, the project estimated that a full-scale facility at various installations ranging from 10,000 personnel to 40,000 personnel had the capability to annually produce 25,000 gasoline gallon equivalents of biomethane (at a 10,000 personnel base), 50,000 gasoline gallon equivalents of biomethane (20,000 personnel base), and 99,000 gasoline gallon equivalents of biomethane at a 40,000 personnel base. At current gas prices this equated to an estimated food waste disposal cost as low as $50 per wet ton at the 10,000-personnel base and $22 per wet ton at the 20,000-personnel base. For the larger base of 40,000 personnel, the project projected to provide revenue at $2 per wet ton of food waste generated. In comparison, the cost of landfilling across the United States is $50 per wet ton and composting costs range from $29 to $52 per wet ton.

3.0 DRIVERS

There are many drivers for this project. As the costs obtained from the study indicate, there is an economic driver to implement the project. In addition, there are regulatory drivers as listed below.

- The DoD Strategic Sustainability Performance Plan provides an approach toward meeting these requirements which includes a focus on: 1) reducing energy needs and reliance on fossil fuels; and 2) water resources management.
- American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 189.1-2009, Leadership in Energy and Environmental Design (LEED) and various Energy Policy Acts all have required more sustainable use of energy.
- The Army has implemented a Net-Zero installations policy seeking to increase and improve sustainability on installations.
- In addition, several other orders and acts promote energy sustainability and minimization of waste generation including:
- EPACT 2005
    - EO 13423
    - 10 United States Code 2577
    - Energy Independence and Security Act 2007
    - FY2008 NDAA
    - Pollution Prevention Act of 1990
    - DoD Instruction 4715.4 “Pollution Prevention”
    - DoD Integrated Solid Waste Management Policy

4.0 IMPLEMENTATION CHALLENGES

This study showed that there are considerable opportunities for food waste digestion at DoD installations. However, there are a number of challenges to get the project going. These challenges fall into the following categories: risk, familiarity with technology and compatibility with installation mission, costing gap analysis, and local conditions and markets.

4.1 RISK

The project requires significant risk of capital. In total the project is estimated to cost between $930,000 to $2.4 million depending on the size of the facility. Although, the program showed that the project was technologically feasible and met nearly all of the performance objectives, the anaerobic digesters showed signs of stress in the Phase III part of the study. Further, Phase IV was not run to full completion and quasi-steady state conditions were not achieved in Phase IV. Additionally, mono-digestion of food waste is not yet common throughout the country. Long term analysis of the impacts to pumping equipment and other components of the digestion were not determined in the study.

Additionally, the economics of the process are related to current market conditions. Some of the market risks are mitigated because gasoline prices are currently low relative to recent past. However, gasoline prices are extremely volatile. The costs are much less sensitive to electrical power costs relative to gasoline prices, but a steep rise in power costs may impact the financial viability of the project. Finally, the vehicle fuel cost contains fuel taxes. This is important as some states, such as Oregon, are moving away from fuel taxes toward taxing vehicles on miles driven. This could reduce the cost savings of the project.

4.2 FAMILIARITY WITH TECHNOLOGY AND COMPATIBILITY WITH FACILITY MISSION

Although anaerobic digestion is ubiquitous at wastewater treatment plants, they do not exist in great numbers at DoD installations. As such, implementation may require new staff or additional training of staff for the technology. Because the skillset will be unlike most other jobs on the installation, it may be necessary to train more than one staff member in the position so that the job is covered during vacations, sick leave, and staff turnover. Additionally, staffing projections for the facility do not warrant a full time position. Therefore, the staff dedicated to this will likely have other jobs.

4.3 COSTING GAP ANALYSIS

The final report on this project identified that the technology was cost competitive with current food waste disposal methods. However, it also identified two cost components that were not included in the technology. One of the end products of the study is a compressed biomethane, similar to compressed natural gas that can fuel a vehicle. The cost components of the study to not cover the cost of vehicle conversion to run on compressed biomethane. The cost of vehicle conversion is not widely published. However, the Honda Civic is currently offered with a gasoline engine or can be purchased to run on CNG. Based on the Manufacturers Suggested Retail Price (available from Honda.com) a Honda Civic with a CNG engine likely costs between $6,000 and

$8,000 more than a gasoline engine. Assuming an average fuel economy of 30 miles per gallon and around 7000 miles driven annually from a typical fleet vehicle, a base may need to retrofit or newly purchase between 110 to 430 (depending on installation size) CNG vehicles to fully utilize the biomethane produced from the digesters. As a result the missing cost for this conversion is likely in the range of $750,000 to $3,000,000 for a vehicle fleet capable of fully utilizing the biomethane.

Another cost not identified was the digestate disposal cost. Due to the significant solids destruction of the food waste in the anaerobic digester, the digestate could likely flow to a local water reclamation facility in the sewer system. As such, there are no expected transportation or hauling costs associated with the digestate. However, the local water reclamation facility may consider this a high strength discharge and elect to charge a service fee for handling it. Service fees from wastewater utilities vary depending on local conditions.

4.4 LOCAL CONDITIONS AND MARKETS

Local conditions and markets should be weighed prior to commencing with a food waste digester project. The costs for landfilling and composting as well as energy and gasoline prices were based on national averages. Local conditions may vary and impact the economic feasibility. In locations where gasoline tends to be higher, such as California, the anaerobic digestion process may be more economically feasible. However, in locations with low gasoline costs, high power costs, and low landfill tipping fees, the project may not be economically competitive.

Local staff acceptance may impact the ability of the project to succeed. In locations where the facility is a long way from typical transportation destinations, the reduced range of a CNG vehicle may not be acceptable. CNG vehicles typically have less than half the range compared to gasoline fueled vehicles. As such, drivers of the vehicles will have less flexibility for long trips. Additionally, the projections identify the production of between 68 gasoline gallon equivalents per day at a 10,000 personnel base to 270 gasoline gallon equivalents per day at the 40,000 personnel base. Installations should consider current fuel demands prior to investment. In the event that there is no demand for the converted biogas then this excess fuel would need to be flared and have no value to offset capital purchases.

5.0 ALTERNATE PROJECT CONSIDERATIONS

Section 4.0 discussed the challenges to implementing the project as a standalone facility at a DoD installation. As a result, it may be appropriate to explore alternate options. More proven than mono-digestion of food waste is co-digestion of food waste with wastewater solids. Co-digestion has become quite common at wastewater treatment plants as these facilities look to maximize their existing assets in their anaerobic digestion and energy systems. The facilities typically, receive a tipping fee for receiving the material and then are able to maximize the output of their engine generation equipment.

Co-digestion would be an option for any DoD installation that generates food waste. It would be a particular advantage for facilities that already have anaerobic digesters, like the United States Air Force Academy and Joint Base Lewis McCord. Although their facilities may not currently have energy production equipment such as biogas scrubbers and vehicle fueling systems, the costs of implementing these features would be reduced compared to a mono-digestion facility that would require the construction of the digestion facilities in addition to the energy recovery facilities. Further, the co-digestion within a DoD installation that already has anaerobic digestion would increase the total energy value in the biogas over a mono-digestion facility that processes only food waste or only municipal wastewater solids. This would effectively make more technologies available for utilization including combined heat and power generation facilities. Finally, the use of co-digestion eliminates the need for a sewer discharge fee that may be required to release digestate into a municipally owned wastewater treatment plant.

Prior to implementing co-digestion at a DoD-owned wastewater treatment plant the facility would need to be checked to determine if the existing digesters have capacity and ensure that the food waste does not impact the wastewater biosolids that would bring them out of compliance with existing regulations.

Since very few DoD installations have anaerobic digestion facilities on site, another option would be to investigate partnering with a local municipality. Many municipalities are already co-digesting within their facilities and more are studying the process. Although, implementation of co-digestion at a DoD installation may have limited impact in the accounting of greenhouse gases as the wastewater treatment utility would likely earn the greenhouse gas credits, the DoD installation may be able to reduce costs compared to traditional methods of food waste disposal. DoD installations should explore these partnerships and assess if a requested tipping fee for the food waste disposal is less than the current contracts for landfilling or for composting. Of note, the wastewater utility may require some pre-processing or pre-sorting of the food waste prior to delivery. It would be important to understand what the utility would be like with regard to the food waste.

6.0 IMPLEMENTATION DESIGN RECOMMENDATIONS

Implementation of a food waste digestion or co-digestion facility should be well thought out and planned. **Figure 1** shows a potential decision tree for assessing if co-digestion or mono digestion of food waste is appropriate for a DoD installation. Based on the logic diagram, there are four potential outcomes (1) co-digestion at a DoD owned facility, (2) mono-digestion at a DoD owned facility, (3) co-digestion at a partner facility, or (4) continue with current food waste disposal methods.

This decision tree is only a quick tool to determine if food waste digestion may be appropriate. It should be noted that prior to commencing any food waste digestion program, a detailed study be conducted for the specific DoD installation. The decision tree identifies that a partnership with a local agency should be investigated, then negotiations should be conducted. Negotiations should target a tipping fee that is less than the results of the study conclusions. For example, facilities with populations less than 10,000 should consider tipping fees less than approximately $58 per wet ton or less than the facilities current disposal costs. Facilities around 20,000 should consider tipping fees less than $22 per wet ton. Large facilities should only consider partnerships with agencies willing to take the food waste at essentially no cost. It is likely that a site specific study will be needed to confirm these values and assist in negotiations. The site specific study would need to identify costs for the facility assuming a fully independent handling and handling of food waste and recovery of the generated biogas at the base.

Upon confirmation that food waste digestion provides a benefit, the installation should consider a number of factors in the facility design. A list of design criteria for a full-scale system is as shown in **Table 1**.

Table 1 presents the key results from this study that can be used to size equipment and facilities for an independent food waste handling system. It should be noted that **Table 1** does not include the influent characteristics of the food waste. These characteristics should be assessed based on actual food waste data from the plant. The researchers recognize that the food waste generated at the Air Force Academy and used as the basis for this study may be different than at other facilities. Food waste characteristics will affect digester performance but COD and SELR were determined to be a useful parameters for evaluating food waste suitability. In addition, experience with co-digestion of food waste also suggests a minimum COD of 20,000 mg/L with the optimum > 50,000 mg/L (Hare 2016). The minimum VS/TS value is 65% with the optimum being > 85%. Also refer to Appendix C in the Final Report (Evans et al. 2016) for information relevant to desired waste stream characteristics. Further, the processing applied at the Air Force Academy, specifically the grinder and pulper, may not exist at all facilities. As a result, the facility will need to work with potential vendors of food waste pulping and grinding systems. These vendors are likely to process the food waste differently, which may have impacts on the food waste concentration and other characteristics.

Figure 1. Decision tree for evaluation of anaerobic food waste digestion options.

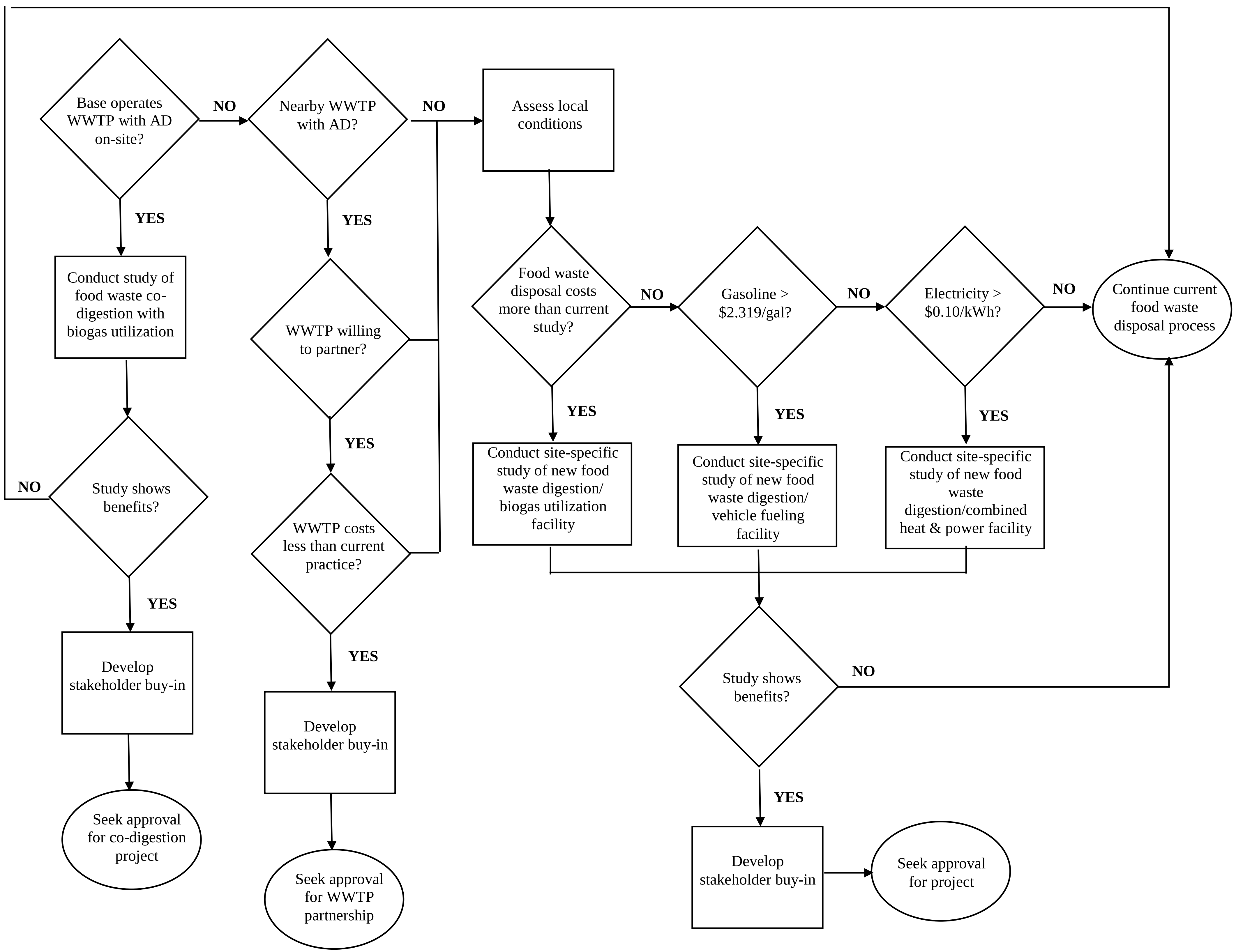

Table 1. Design criteria.

Parameter	Suggested Design Value	Comments
Methane Production (VS basis)	400 L CH_4/kg VS loaded	Use design value to predict methane production from digester. Use for sizing gas utilization equipment and determining potential revenues and offsets from biogas utilization.
Methane Production (COD basis)	250 CH_4/kg COD loaded	Use design value to predict methane production from digester. Use for sizing gas utilization equipment and determining potential revenues and offsets from biogas utilization.
Specific COD loading rate (SELR)	0.44 g-COD/g-VSS/day	Use design value for sizing the anaerobic digestion facilities.
pH	7.8	Design value for understanding operational pH in digester.
TS Reduction	78%	Use design value for projecting solids to be disposed after process.
VSS Reduction	92%	Use in combination with SELR to size anaerobic digestion facilities.
Biogas CH_4 Content	60%	Use in combination with methane production to determine size of required digester gas piping and other digester gas conveyance system, flares, etc.
Biogas H_2S Content	2,900 mg/m^3	Use to size hydrogen sulfide removal systems.

7.0 LESSONS LEARNED

Overall, the pilot digestion system was determined to be operationally friendly once it was up in running and the troubleshooting period was over. A full-scale facility should have less problems and troubleshooting requirements compared to the pilot. This is in part because a full-scale system would likely use larger pumps, with larger clearances, that are less susceptible to plugging. Further, there are many mechanical grinding equipment that are available and marketed to the wastewater treatment industry. These equipment tend to be sized for full-scale installations and are not easily deployed at the pilot scale.

Safety is the primary concern with a digestion process and the hydrogen sulfide release that occurred in the pilot facility necessitates that a full-scale facility be designed to mitigate potential safety hazards. As with pilot scale facility, it is prudent to construct the digestion facilities in compliance with the National Fire Protection Association (NFPA) publication 820. Although, this publication is for wastewater treatment facilities there is no equivalent publication for a food waste system. NFPA 820 will dictate the electrical classification for equipment, provide design requirements for heating and ventilation systems, and specify the monitoring requirements. NFPA 820 doesn’t specifically address hydrogen sulfide.

This study showed that solids destruction in food waste digestion is high compared to municipal wastewater treatment plant digesters. As a result, the stability of the digestion process was challenging to maintain in the third phase of the study. To compensate for the high solids destruction and loss of alkalinity, CDM Smith conducted Phase IV of the study. Phase IV utilized the digestate from the effluent of the digestion process to dilute the food waste to a concentration deemed to be pumpable. This effectively recycled solids and alkalinity back to the digesters and appeared to mitigate the stability issues in Phase III. As a result, future projects should consider using digestate to dilute the food waste solids for pumpability.

8.0 REFERENCES

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